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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H02K 9/00 | A2

(11) International Publication Number: WO 98/28833

(43) International Publication Date: 2 July 1998 (02.07.98)

(21) International Application Number: PCT/SE97/02146

(22) International Filing Date: 18 December 1997 (18.12.97)

(30) Priority Data:
9604812-9 20 December 1996 (20.12.96) SE

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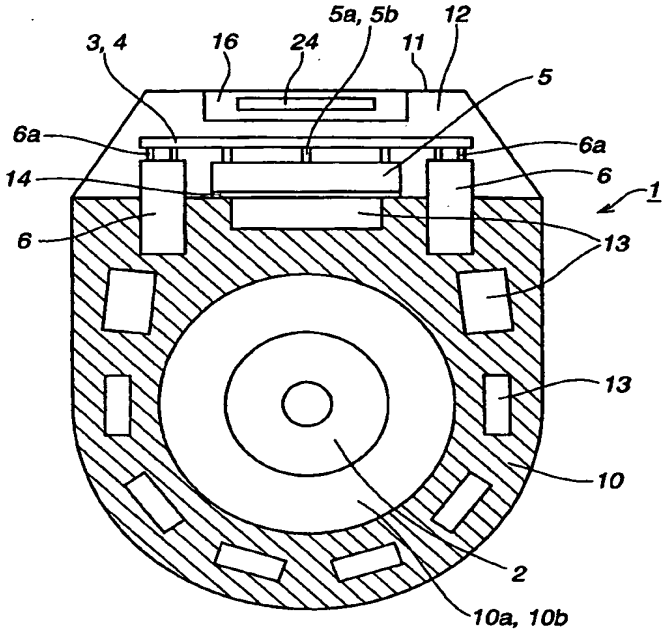
(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
In English translation (filed in Swedish).
Without international search report and to be republished upon receipt of that report.

(54) Title: A DEVICE COMPRISING AN ELECTRIC MACHINE AND CONTROL EQUIPMENT ASSOCIATED THEREWITH

(57) Abstract

A device comprising an ac machine (1) and control equipment connected thereto, the control equipment comprising heat-generating components such as power semiconductors (5) and other electric components (6). The ac machine comprises a stator body (10) with a cooling channel (13) integrated thereinto for conducting a coolant for cooling the heat-generating components and the ac machine. The cooling channel exhibits an opening towards an outer surface of the stator body, which outer surface limits the stator body in its radial direction, and at least the power semiconductors are arranged in a power semiconductor module (5) with a bottom plate (14), and the power semiconductor module is applied to the stator body over said opening in the cooling channel such that the bottom plate constitutes part of a wall surrounding the cooling channel.



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A device comprising an electric machine and control equipment associated therewith

TECHNICAL FIELD

The present invention relates to a device comprising an electric alternating-current machine (or ac machine) and control equipment associated therewith. More particularly, the invention relates to an ac machine, with control equipment integrated therewith, of the type which comprises a cooling system which is common to at least parts of the control equipment and the ac machine. The ac machine may function both as a generator for generation of an electric voltage and as a motor for driving, for example, an electrically operated vehicle.

BACKGROUND ART

Control equipment for an electric machine of the kind to which the invention relates usually comprises power semiconductors, control electronics and other electric components such as, for example, capacitors connected to the main circuits of the control equipment, that is, the circuits which are connected to the windings of the electric machine.

The control equipment is normally divided into several modules such that that the power semiconductors are arranged separately, the control electronics separately and other electric components separately. The modules are normally arranged as separate boxes or cabinets placed at a distance from the ac machine and connected thereto by means of cables and contact devices. The electric components generate heat and, for dissipation of this heat, they are usually provided with separate cooling systems where cooling takes place by means of oil, air or water.

When using such electric ac machines in a vehicle, this separate cooling and location of the control equipment

entails a difficulty. In the event that the control equipment is not sufficiently shielded from the electric machine, problems with electromagnetic disturbance may arise, thus obtaining a system with a non-optimum construction. To circumvent this difficulty, different proposals for location of the electric control equipment in the vicinity of or integrated with the electric machine have been put forward. The advantages of these proposals have been limited because the electric machine and the power semiconductors and other electric components in the control equipment have not been cooled by a common cooling system.

US 5,491,370 describes a unit where an electric machine and a power semiconductor associated therewith are cooled by a common cooling system. For achieving cooling of both the power semiconductors and the electric machine by means of one and the same cooling system, the power semiconductors are arranged in immediate proximity to the exterior of a housing surrounding the machine. In the housing a helical cooling channel is arranged, in which coolant flows for cooling the electric machine. On the outside of the housing and adjacent to the cooling channel, the power semiconductors are placed. To ensure sufficient cooling of the power semiconductors, these are preferably located at a plane, outer surface of the housing.

The advantage of the embodiment shown in US 5,491,370 is limited since no direct cooling of the power semiconductors is obtained but only an indirect cooling. To ensure that sufficient cooling of the power semiconductors is obtained, special arrangements are required, such as location of the power semiconductors on a plane, outer surface of the housing.

SUMMARY OF THE INVENTION, ADVANTAGES

The present invention relates to a device comprising an electric machine and control equipment associated there-

with, and to an improved arrangement for cooling thereof. This arrangement is achieved with the aid of the characteristic features stated in the characterizing part of claim 1.

The ac machine comprises cooling channels which are integrated into a stator body and in which a coolant flows. A lid is connected to the stator body. Between the lid and the stator body there is arranged a module with power semiconductors. Together with capacitors and a control card, the power semiconductor module forms a converter. The power semiconductor module is arranged connected to the cooling channel in such a way that the power semiconductor module is directly cooled through the coolant flowing in the cooling channel.

An advantageous use of the electric ac machine according to the invention is as a drive motor in an electrically operated vehicle. Another possible use of the electric machine according to the invention is at very high speeds, for example in a power unit in which a gas turbine is connected directly to a high-speed generator which is allowed to feed the actual load via the control equipment. This type of use arises, for example, when driving a vehicle of hybrid type. Especially when using the electric machine in vehicles, the requirement that the weight and size of the machine shall be minimized is increased. The machine may alternatively be used in an electric streetcar or in an electrically operated truck.

The advantage of the invention is that the ac machine, which is integrated with control equipment, comprises a cooling system for direct cooling by means of a liquid of both power semiconductors, other electric components in the control equipment and the machine. The coolant is preferably in the form of water with addition of an antifreezing agent. The direct cooling implies that the cooling capacity is increased while at the same time the weight and size of the unit may be reduced. The increased cooling capacity

also implies that modules comprising a plurality of power semiconductors may be allowed in the ac machine since sufficient cooling thereof may be achieved. Another advantage of the present invention is that the electric components included in the control equipment need not, for safe cooling, be arranged on surfaces provided therefor but may be arranged in direct contact with the flowing medium. In this way, the heat transfer is considerably increased between the components of the control equipment and the coolant. Further, the need of a thermally conducting paste or the like is eliminated.

The availability of very compact power semiconductor modules means that the advantage of the invention is further increased with respect to weight and space saving. In the embodiment described, a power semiconductor module comprising a plurality of IGBT type (Insulated Gate Bipolar Transistor) power semiconductors, freewheeling diodes, drive circuits and protective functions is used.

One advantage of the above-mentioned compact power semiconductor modules is that space is saved such that other electric components, such as capacitors, may be placed in the stator body in close proximity to the cooling channel or in direct contact with coolant for cooling flowing in the cooling channel.

Another advantage is that the number and the length of the connection components, necessary for the function of the electric machine, for example in the form of cables, may be reduced, whereby the inductance is reduced, which in turn reduces problems with overvoltages. Likewise, the number of contact devices may be reduced, whereby problems with electromagnetic disturbances, as well as the costs therefor, may be reduced.

The device according to the invention is particularly advantageous in a drive system which, in addition to the electric ac machine with integrated control equipment,

comprises a trans-shaft and a mechanical transmission. This drive system may be integrated to a very large extent and may thus be made very compact. Such a drive system is advantageously installed in an electrically operated vehicle. In case the vehicle is a hybrid-type vehicle, the installation of such a drive system is extra advantageous since the requirement for minimization of such equipment here is extra high.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in greater detail with reference to the accompanying drawings.

Figure 1a shows an example of how an electric machine is connected to a power semiconductor module during motor operation.

Figure 1b shows an example of how an electric machine is connected to a power semiconductor module during generator operation.

Figure 2 shows in perspective view a power semiconductor module, known per se, connected to a busbar and to stator winding terminals from an ac machine.

Figure 3a shows a partially sectioned electric machine with integrated electronics.

Figure 3b shows in a section A-A in Figure 3a an example of an electric machine according to the invention.

Figure 4 shows in a cross section an alternative method of integrating a capacitor in immediate proximity to a coolant channel in a stator body.

Figure 5 shows in a cross section a power semiconductor module mounted to a coolant channel in a stator body.

Figure 6a shows in a cross section an alternative embodiment of a power semiconductor module mounted to a coolant channel in a stator body.

Figure 6b shows a power semiconductor module in a section B-B in Figure 6a.

Figure 7 shows a device according to the invention, integrated with a trans-shaft and a transmission.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1a shows an example where an ac machine 1 comprising a rotor 2 operates as a motor. Direct voltage from an external energy source is fed to the respective + and - connections of a busbar 3, 4. The direct voltage is transformed by means of a power semiconductor module 5 to alternating voltage. The alternating voltage is then fed from the power semiconductor module 5 to each of the three phases, that is, to an alternating-voltage connection 5a of the winding terminal of a stator in the electric machine 1 chosen in the embodiment. Capacitors 6 are arranged in a direct-voltage intermediate link for temporary energy storage and for reduction of harmonics generated in the direct-voltage intermediate link. The direct-voltage intermediate link is adapted to feed direct voltage to the direct-voltage connections 5b of the power semiconductor module 5. A control electronic unit 24 is connected to the power semiconductor module 5.

Figure 1b shows an example in which the ac machine 1 comprising the rotor 2 operates as a generator. The rotor 2 may, for example, be driven by a gas turbine 8. Each winding phase of the electric machine 1 is connected to the alternating-voltage connections 5a of the power semiconductor module 5. The alternating voltage is transformed by means of the power semiconductor module 5 into direct voltage which is forwarded to the respective + and - connections of the busbar 3, 4 to be forwarded to the

prevailing load, which, for example, may be a drive system in a hybrid vehicle.

Figures 1a and 1b show pieces of control equipment connected in a manner known per se. Normally, the power semiconductor module 5 is placed physically separated from the control electronic unit 24 and the electric components 6. According to the present invention, however, they are integrated with each other to a large extent. This is clear from Figure 3.

Figure 2 shows a power semiconductor module 5, known per se, in which a plurality of power semiconductors are arranged. The power semiconductor module 5 comprises the members 5a connected to the stator winding terminals of the ac machine, and the members 5b for connection to the busbar 3, 4. The capacitors 6 comprise capacitor connections 6a for connection to the busbar 3, 4. The connection between the direct-voltage connections 5b and the capacitor connections 6a is made in the busbar 3, 4 which comprises two copper plates which are substantially parallel to each other and which are insulated from each other by a thin insulating layer 9. The advantage of this embodiment of the busbar 3, 4 is that plane plates and the insulation 9 are simple to manufacture. Further, the inductances may be kept very low because of the short conductors, which reduces the risk of overvoltages. An additional advantage is that the total overall height of the electric ac machine 1 may be further reduced.

Figures 3a and 3b show an example of an electric machine 1 according to the invention. The electric machine 1 comprises the rotor 2 and a stator body 10. A lid 11 is connected to the stator body 10 in such a way that a cavity 12 is formed.

The stator body 10 comprises a cavity which is substantially filled by a laminated stator core 10a, a stator winding 10b and the rotor 2. A cooling channel 13 is

integrated into the stator body 10 and extends in a loop which is substantially arranged in the axial direction of the machine 1. A coolant, preferably water, is adapted to flow in the cooling channel 13. In immediate proximity to the cooling channel 13, the power semiconductor module 5 is arranged. Alternatively, the cooling channel 13 may be divided into two or more parallel loops. In an advantageous embodiment, the cooling channel 13 is arranged such that the coolant first passes past the power semiconductor module 5 for achieving good cooling thereof. Thereafter, the coolant cools the rest of the electric machine 1.

As mentioned above, the power semiconductor module 5 comprises a plurality of power semiconductors. The power semiconductors are arranged on a common bottom plate 14. The bottom plate 14 is made of a material with good thermal conductivity, for example copper. The cooling channel 13, which is integrated with the stator body 10, efficiently cools both the ac machine 1 and the power semiconductor module 5.

Further, Figures 3a, 3b show that the capacitors 6 are arranged partially in the cavity 12, partially in the stator body 10. The shown location of the capacitors 6, in close proximity to the power semiconductor module 5, also implies that a low-inductance circuit may be formed since the wiring may be minimized. Further, by this location of the capacitors 6 in the stator body 10, an efficient cooling thereof may be accomplished.

An alternative location of the capacitors 6 is shown in Figure 4. In this case, the shown capacitor 6 is arranged in immediate proximity to the cooling channel 13 for direct cooling thereof. To avoid leakage of coolant from the coolant channel 13, the capacitor 6 is arranged with some form of sealing 15a between the stator body 10 and the capacitor 6. In the embodiment chosen, this seal 15a is in the form of an O-ring seal.

It is further clear from Figures 3a, 3b that the lid 11 comprises a space 16 in which is arranged a control card with the control electronic unit 24 for control of the power semiconductor module 5. The control card, which hereinafter will be designated with the reference numeral 24, is adapted to receive and convert externally supplied control signals. The control card 24 is arranged, by means of a contact device 24a, to deliver the converted signals in the form of, for example, optical or electric signals, to the power semiconductor module 5 for controlling via the module 5, in a manner known per se, in dependence on the control signals from the control card 24, for example the torque and speed delivered by the electric machine 1. The control card 24 is arranged in the space 16 in such a way that it is shielded from the surrounding electronics, such as the power semiconductor module 5, to avoid electromagnetic disturbances therefrom. The space 16 is limited, for example, by aluminium which constitutes a good shielding of the control card 24.

Figure 5 shows the power semiconductor 5 and the cooling channel 13 in more detail. The power semiconductor 5 is secured to the stator body 10. To avoid leakage of coolant from the coolant channel 13, the power semiconductor module 5 is arranged with some form of sealing 15b between the stator body 10 and the bottom plate 14. In the embodiment chosen, this seal 15b is made as an O-ring seal. The power semiconductor module 5 is thus arranged in the stator body 10 and in direct contact with the coolant flowing in the cooling channel 13. The embodiment thus lacks a cooling plate especially designed for the power semiconductor module 5 and arranged between the cooling channel 13 and the power semiconductor module 5. The bottom plate 14 is instead arranged in an opening (not shown) in the cooling channel 13 in such a way that it constitutes part of a wall which surrounds the cooling channel 13.

Figures 6a and 6b show an alternative embodiment of the bottom plate 14 of the power semiconductor module 5. The bottom plate 14 in the chosen embodiment is made with cooling flanges 17. By forming the bottom plate 14 with cooling flanges 17, an additionally more efficient cooling of the power semiconductor module 5 is obtained. The cooling flanges 17 are formed as a plurality of substantially straight bars, which are substantially parallel to each other and distributed over the surface of the bottom plate 14. The cooling flanges 17 are adapted to extend inwardly towards the central part of the cooling channel 13.

In the embodiment chosen, a three-phase ac machine 1 is shown. The invention is, of course, also applicable to electric machines 1 with both fewer and more phases.

Figure 7 schematically shows a drive system comprising the ac machine 1 with integrated control equipment, described above, a trans-shaft arrangement 18 and a mechanical transmission 19 comprising a reduction gear 20 and a differential 21. This very compact drive system is advantageously used in a hybrid-type vehicle, symbolized by the drive shaft 22 and the wheel 23.

CLAIMS

1. A device comprising an ac machine (1) and control equipment connected thereto, the control equipment comprising heat-generating components such as power semiconductors (5) and other electric components (6), the ac machine (1) comprising a stator body (10) with a cooling channel (13) integrated thereinto for conducting a coolant for cooling the heat-generating components (5, 6) and the ac machine (1), **characterized** in that the cooling channel exhibits an opening towards an outer surface of the stator body, which outer surface limits the stator body in its radial direction, that at least the power semiconductors (5) are arranged in a power semiconductor module (5) with a bottom plate (14), and that the power semiconductor module is applied to the stator body over said opening in the cooling channel such that the bottom plate constitutes part of a wall surrounding the cooling channel.

2. A device according to claim 1, **characterized** in that the bottom plate (14) is provided with cooling flanges (17) adapted to extent inwards towards the central part of the cooling channel (13).

3. A device according to claim 2, **characterized** in that the cooling flanges (17) are elongated and arranged as substantially straight bars which are substantially parallel to each other.

4. A device according to any of claims 1-3, wherein the control equipment comprises at least one capacitor (5) comprised in a direct-voltage intermediate link for feeding the power semiconductor module, **characterized** in that the cooling channel exhibits an opening towards an outer surface of the stator body, and that the capacitor is applied to the stator body over said opening in the cooling channel such that the capacitor constitutes part of a wall surrounding the cooling channel.

5. A device according to any of the preceding claims, **characterized** in that the coolant consists of a liquid, preferably water mixed with an antifreezing agent.

6. A device according to any of the preceding claims, **characterized** in that a lid (11) is connected to the stator body (10) and that, in a space (12) formed between the lid (11) and the stator body (10), a control card (24) is arranged for controlling the electric machine (1) and the power semiconductor module (5).

7. A drive system for driving a vehicle, **characterized** in that it comprises a device according to any of claims 1-6.

8. A drive system according to claim 7, **characterized** in that it comprises a trans-shaft arrangement (18) and a mechanical transmission (19) comprising a reduction gear (20) and a differential (21).

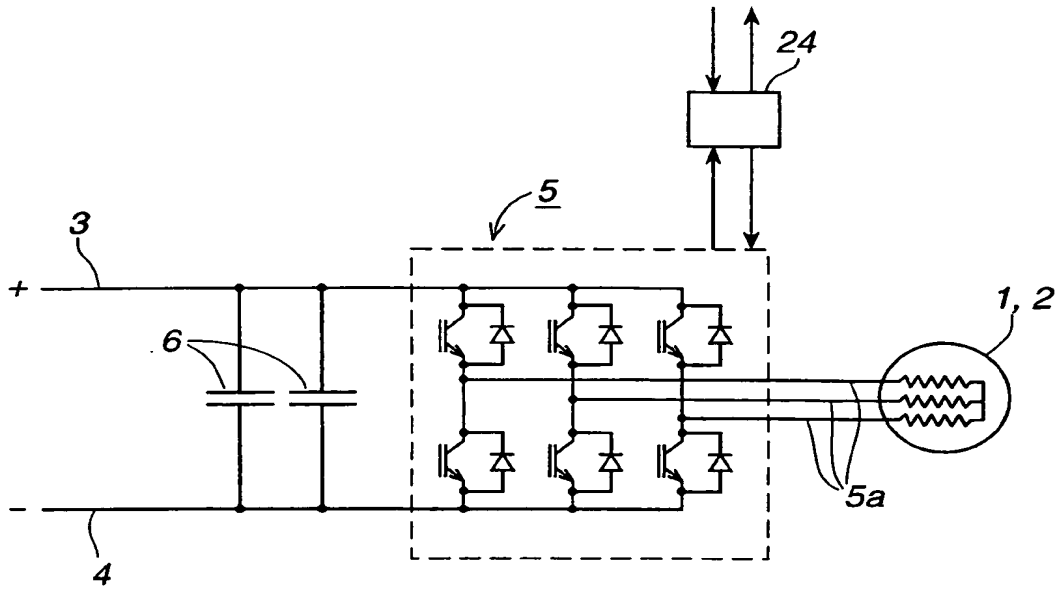


Fig. 1a

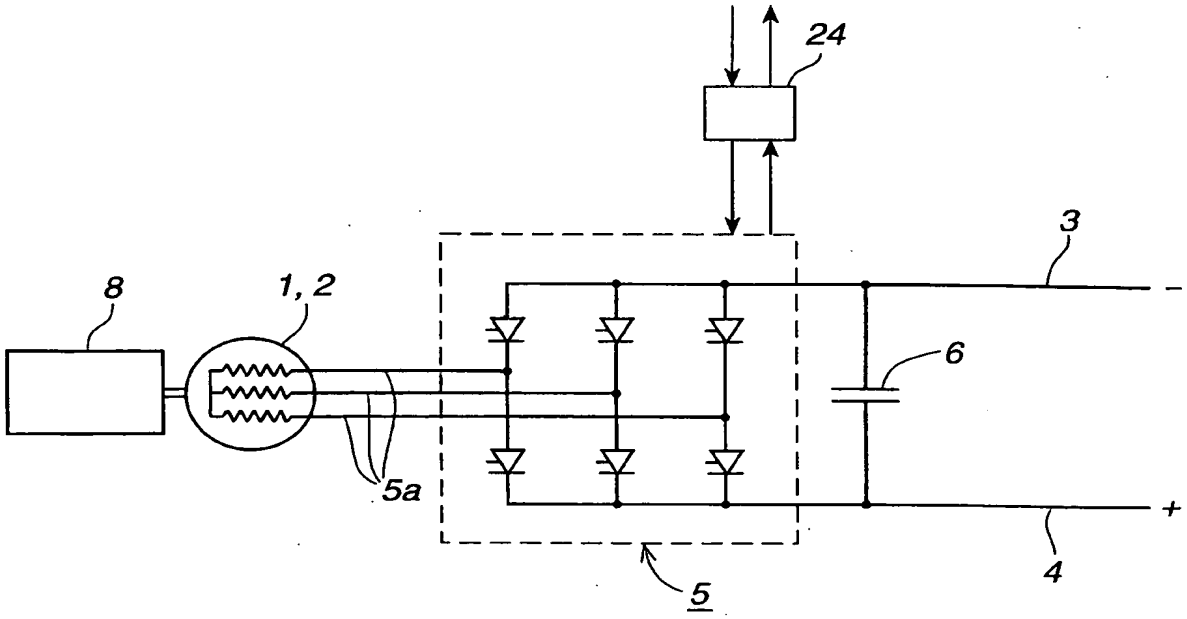


Fig. 1b

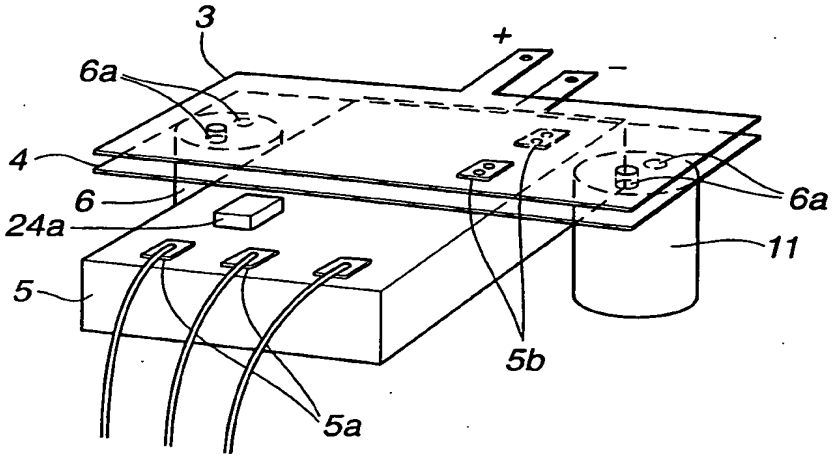


Fig. 2

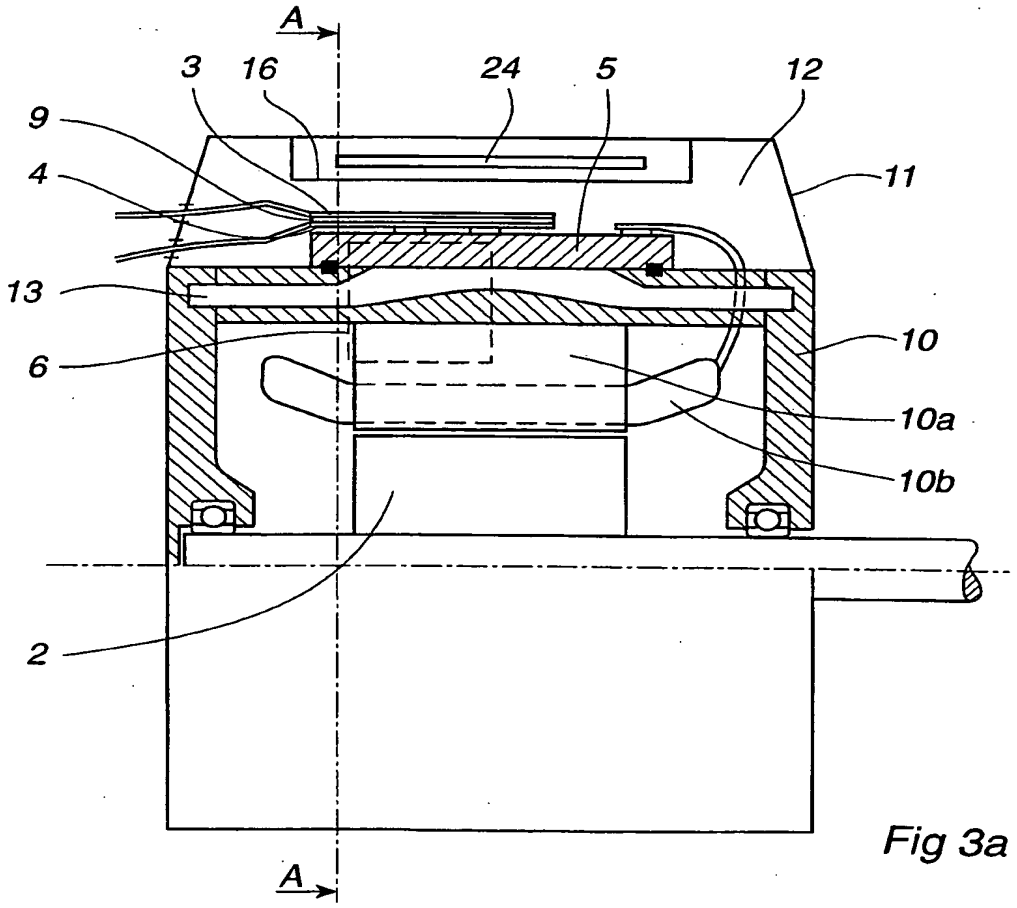


Fig 3a

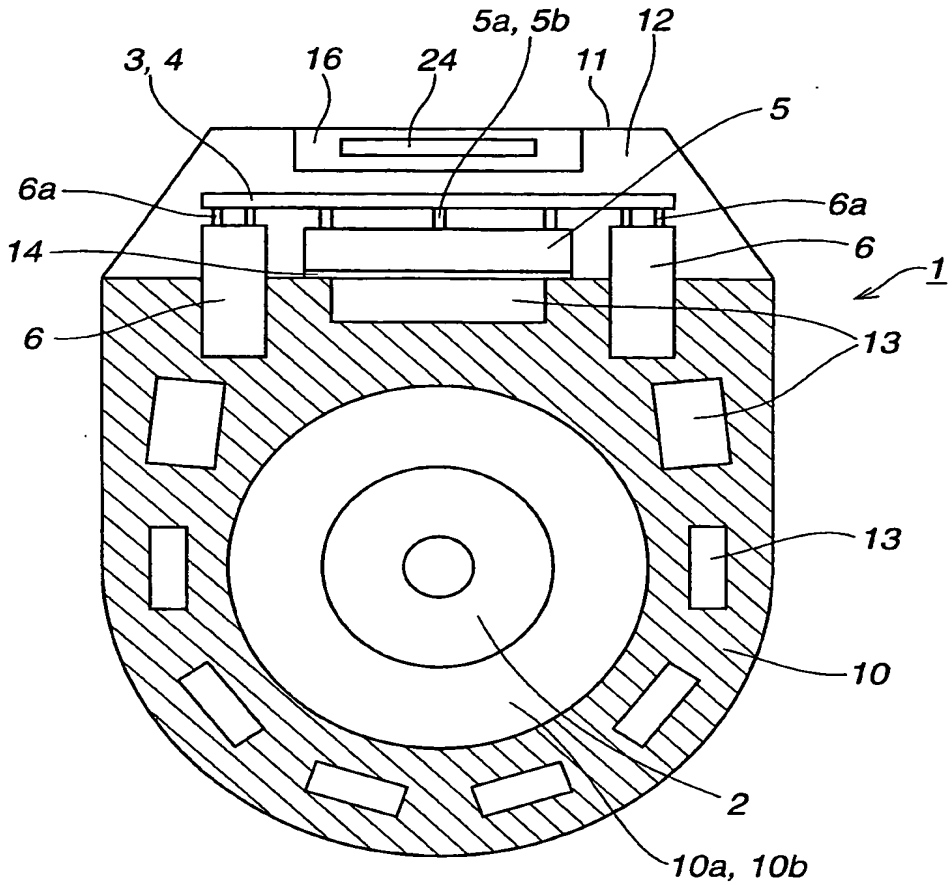


Fig. 3b

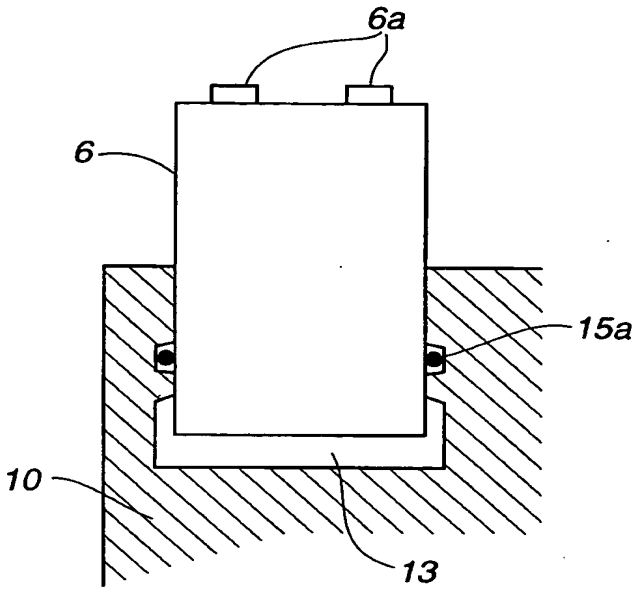


Fig. 4

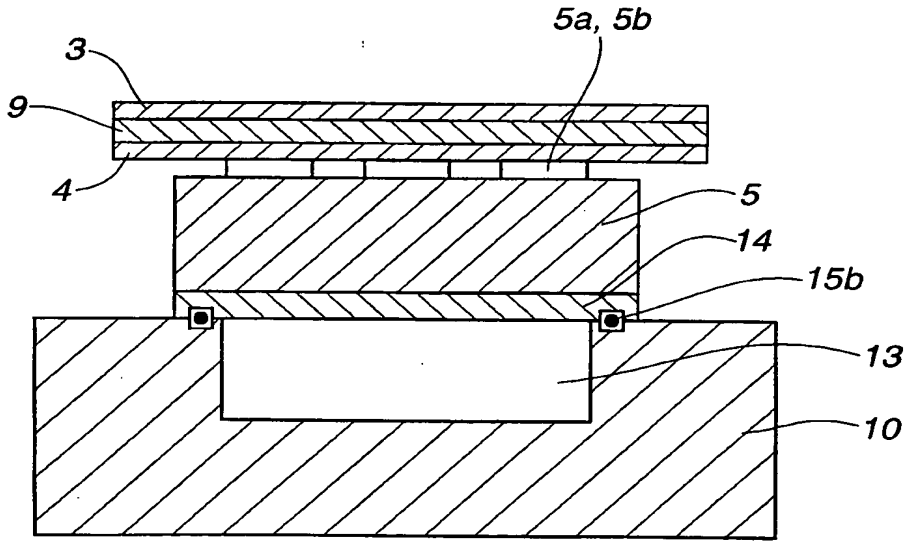


Fig. 5

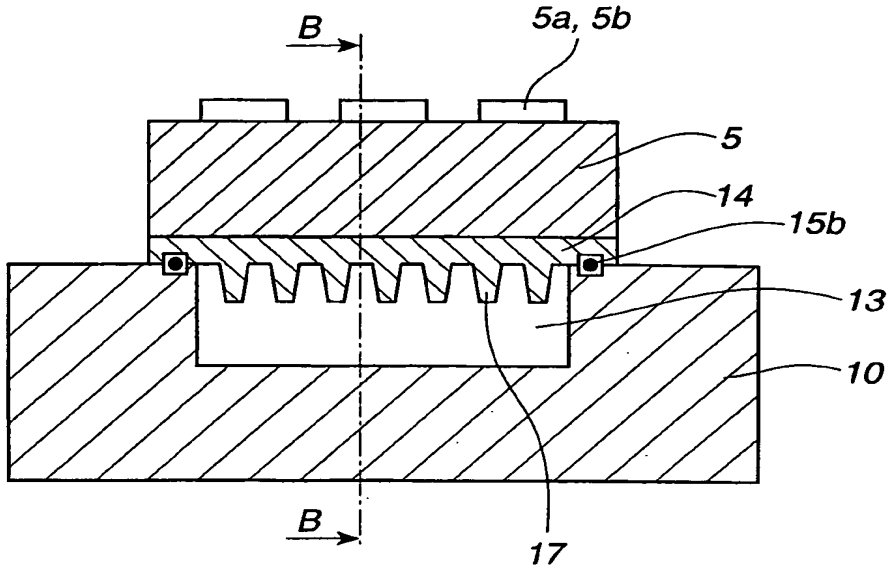


Fig. 6a

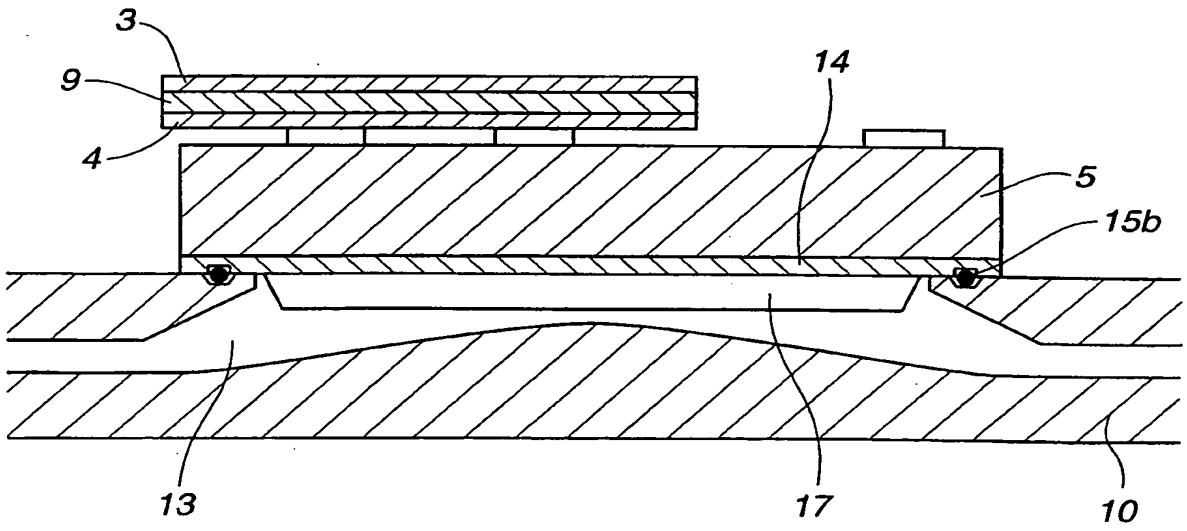
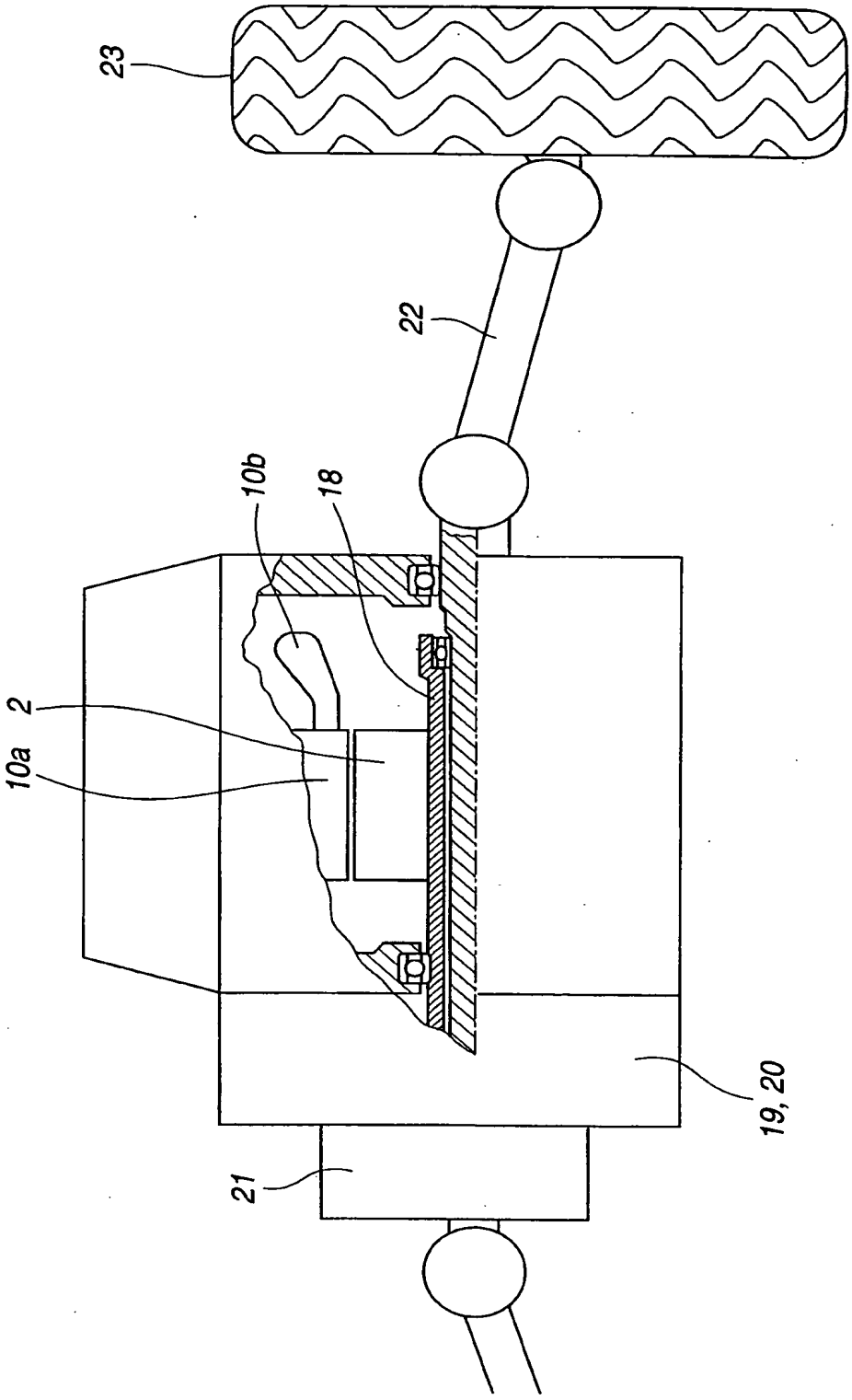


Fig. 6b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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H02K 9/00, 11/00 | A3

(11) International Publication Number: **WO 98/28833**

(43) International Publication Date: 2 July 1998 (02.07.98)

(21) International Application Number: PCT/SE97/02146

(22) International Filing Date: 18 December 1997 (18.12.97)

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(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published

With international search report.

Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

In English translation (filed in Swedish).

(88) Date of publication of the international search report:
27 August 1998 (27.08.98)

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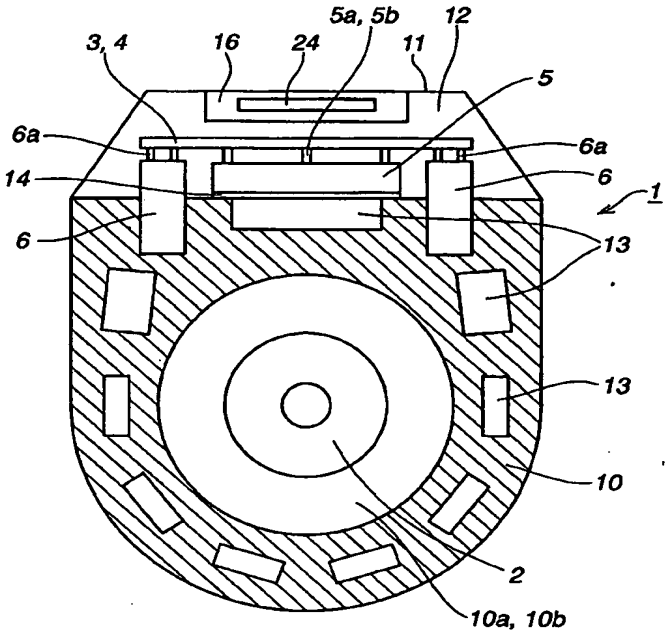

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International application No.
PCT/SE 97/02146

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 9/00, H02K 11/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 4442867 A1 (FICHTEL & SACHS AG), 13 June 1996 (13.06.96), column 8, line 22 - line 50, figure 1	1-3,6-8
A	--	4-5
A	US 5491370 A (E.D.SCHNEIDER ET AL), 13 February 1996 (13.02.96), figures 3,4, abstract	1-8
A	--	1-8
	US 5585681 A (O.BITSCHE), 17 December 1996 (17.12.96), figure 2, abstract	
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 June 1998	30 -06- 1998
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Anna Theander Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

29/04/98

International application No.
PCT/SE 97/02146

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 4442867 A1	13/06/96	FR 2727654 A,B	07/06/96
		GB 2295730 A	05/06/96
		GB 9524740 D	00/00/00
		US 5678646 A	21/10/97
US 5491370 A	13/02/96	NONE	
US 5585681 A	17/12/96	DE 4417432 A	01/12/94
		FR 2705842 A,B	02/12/94